DESIGN AND DEVELOPMENT OF A THOUGHT CONTROLLED INTELLIGENT ROBOT CHAIR WITH COMMUNICATION AID

SATHEES KUMAR NATARAJ

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by

SATHEES KUMAR NATARAJ
(1240610751)

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LIST OF ABBREVIATIONS

AAC	Augmentative and Alternative Communication
ALS	Amyotrophic Lateral Sclerosis
ANN	Artificial Neural Networks
ANOVA	Analysis of Variance
AP	Average Power
BMI	Brain Machine Interface
BMI-N	Brain Machine Interface for Navigation
BMI-SC	Brain Machine Interface for Speech
CA	Classification Accuracy
CC	Customized Classification
CNS	Central Nervous System
CRP	Corneoretinal Potential
CT	Computational Time
DE	Differentially Enabled
EEG	Electroencephalography
EMG	Electromyogram
EOG	Electrooculogram
ERP	Event Related Potentials
fMRI	Functional Magnetic Resonance Imaging
fNIR	Functional Near-Infrared Imaging
HMI	Human Machine Interface
HOS	Higher Order Statistics
ICA	Independent Component Analysis
IIR	Infinite Impulse Response Filters

IRCC	Intelligent Robot Chair with Communication Aid
IRCC-CC	IRCC System in Customized Classification System
IRCC-CC-TEP	IRCC System for TEP Database in Customized Mode
IRCC-CC-VEP	IRCC System for VEP Database in Customized Mode
IRCC-GC	IRCC System in Generalized Classification System
ITR	Information Transfer Rate
KNN	K-Nearest Neighbor
LDA	Linear Discriminant Analysis
MEG	Magnetoencephalography
MI	Motor Imaginary
MLNN	Multilayer Neural Network
MOH	Ministry of Health Malaysia
MREC	The Medical Research & Ethics Committee
NMD	Neuromuscular Disorders/Diseases
NMRR	National Medical Research Registration
P300	P for positive, 300 for the 300-millisecond delay
PET	Positron Emission Tomography
PSD	Power Spectral Density
QoL	Quality of Life
SC	Speech Communication
SCP	Slow Cortical Potentials
SE	Sensitivity
SNR	Signal to Noise Ratio
SP	Specificity
SSVEP	Steady State Visually Evoked Potentials

SVM	Support Vector Machine
TEP	Thought Evoked Potentials
TTD	Thought Translation Device
TVEPs	Transient VEPs
VEP	Visually Evoked Potentials
WHO	World Health Organization
WSS	Wide Sense Stationary

LIST OF SYMBOLS

α	Alpha band
H_a	Alternative hypothesis
ΔF	Bandwidth
β	Beta band
δ	Delta band
$\gamma 1$	Gamma 1 band
$\gamma 2$	Gamma 2 band
μ	Mean
μ and β rhythm	Sensorimotor rhythms
σ	Standard deviation (SD)
θ	Theta band (4- 8 Hz)
$r_{\delta_i}^{j}$, $r_{\theta_i}^{j}$, $r_{\beta_i}^{j}$, $r_{\alpha_i}^{j}$, $r_{\gamma 1_i}^{j}$ and $r_{\gamma 2_i}^{j}$	Auto-correlation sequence of delta, theta, alpha, beta, gamma-1 and gamma-2 frequency bands.
$r_{\delta_i,\delta_{i+1}}^{j}$, $r_{\theta_i,\theta_{i+1}}^{j}$, $r_{\beta_i,\beta_{i+1}}^{j}$, $r_{\alpha_i,\alpha_{i+1}}^{j}$, $r_{\gamma 1_i,\gamma 1_{i+1}}^{j}$ and $r_{\gamma 2_i,\gamma 2_{i+1}}^{j}$	Cross-correlation sequence of two consecutive frames in each frequency bands (delta, theta, alpha, beta, gamma-1 and gamma-2).
$r_{\delta_i,\theta_i}^{j}$ $r_{\delta_i\alpha_i}^{j}$, $r_{\delta_i\beta_i}^{j}$, $r_{\delta_i\gamma 1_i}^{j}$, $r_{\delta_i\gamma 2_i}^{j}$, $r_{\theta_i\alpha_i}^{j}$, $r_{\theta_i\beta_i}^{j}$, $r_{\theta_i\gamma 1_i}^{j}$, $r_{\theta_i\gamma 2_i}^{j}$, $r_{\alpha_i\beta_i}^{j}$, $r_{\alpha_i\gamma 1_i}^{j}$, $r_{\alpha_i\gamma 2_i}^{j}$, $r_{\beta_i\gamma 1_i}^{j}$, $r_{\beta_i\gamma 2_i}^{j}$, $r_{\gamma 1_i\gamma 2_i}^{j}$	Cross-correlation sequence for the 15 combination of six frequency bands
$r_{T3_iT4_i}^{fb}$, $r_{T3_iC3_i}^{fb}$, $r_{T3_iC4_i}^{fb}$, $r_{T3_iP3_i}^{fb}$, $r_{T3_iP4_i}^{fb}$, $r_{T3_iO1_i}^{fb}$, $r_{T3_iO2_i}^{fb}$, $r_{T4_iC3_i}^{fb}$, $r_{T4_iC4_i}^{fb}$, $r_{T4_iP3_i}^{fb}$, $r_{T4_iP4_i}^{fb}$, $r_{T4_iO1_i}^{fb}$, $r_{T4_iO2_i}^{fb}$, $r_{C3_iC4_i}^{fb}$, $r_{C3_iP3_i}^{fb}$, $r_{C3_iP4_i}^{fb}$, $r_{C3_iO1_i}^{fb}$, $r_{C3_iO2_i}^{fb}$,	Cross-correlation sequence for the 28 combination of eight electrode channels

$r^{fb}_{C4_i\mathrm{P}3_i}, r^{fb}_{C4_i\mathrm{P}4_i}, r^{fb}_{C4_iO1_i}, r^{fb}_{C4_i\mathrm{O}2_i}, r^{fb}_{\mathrm{P}3_i\mathrm{P}4_i}, r^{fb}_{\mathrm{P}3_iO1_i},$ $r^{fb}_{\mathrm{P}3_i\mathrm{O}2_i}, r^{fb}_{\mathrm{P}4_iO1_i}, r^{fb}_{\mathrm{P}4_i\mathrm{O}2_i}, r^{fb}_{O1_i\mathrm{O}2_i}$	
$r_{Y_1Y_2}(h)$	The cross correlation of two length Y deterministic inputs
Ag	Silver metal
AgCl	Salt—silver chloride
$B(f1, f2)$	Bispectrum in the bifrequency (f_1, f_2)
C3 and C4	Central lobe
CP_i^j	Change in powers
DA_i^j	Differential asymmetry
dB	Decibel
df	Degrees of freedom
f_1, f_2	Frequencies
F-value	Critical value for the f distribution
h	Lag
H_0	Null hypothesis
k	Kappa
M	Vector length
M_{CEC}	Mean features of the cross-correlated frame based combination of electrode channels
M_{CF}	Mean features of the Cross-Correlated Two Consecutive Frame based Spectral Bands
M_{CFB}	Mean features of the Cross-Correlated Frame Based Combination of Spectral Bands

M_{CFW}	Mean features of the auto-correlated frame wise spectral bands
O1 and O2	Occipital lobe
P3 and P4	Parietal lobe
p-value	Probability of obtaining test statistical test
RA_i^j	Rational asymmetry
RP_i^j	Relative powers of frequencies
SD_{CEC}	Standard deviation features of the cross-correlated frame based combination of electrode channels
SD_{CF}	Standard deviation features of the Cross-Correlated Two Consecutive Frame based Spectral Bands
SD_{CFB}	Standard deviation features of the cross-correlated frame based combination of spectral bands
SD_{CFW}	Standard deviation features of the auto-correlated frame wise spectral bands
SP_i^j	Sum of the powers
T3 and T4	Temporal lobe
$Y(f)$	Discrete Fourier Transform (DFT) for deterministic signals
$Y*(f_1 + f_2)$	Complex conjugate
YF_i^{j2}	Whole spectrum (0.1 – 100 Hz)
Yf_i^j	Specified frequency band signal

Reka Bentuk dan Pembangunan Sistem Kawalan secara Pemikiran untuk Kerusi Robot Pintar dengan Komunikasi Verbal

ABSTRAK

Pergerakan asas seperti berjalan, dan komunikasi adalah keperluan asas manusia dalam kehidupan seharian. Masyarakat kurang upaya (DE) mempunyai pengehadan perangkap yang berubah antara aktiviti utama atau rumit seperti kelemahan otot-otot, kekejangan, masalah berkaitan pergerakan, strok, masalah penghadaman dan dysarthria. Dalam kes-kes ini, isyarat Electroencephalogram (EEG) digunakan sebagai ukuran pada aktiviti otak yang bertanggungjawab untuk mengawal pergerakan otot voluntari menerusi sistem saraf boleh digunakan untuk membentuk sistem komunikasi atau antara muka mesin otak (BMI). Kajian ini memberi tumpuan kepada analisis pelbagai domain frekuensi algoritma untuk menentukan isyarat-isyarat pelayaran dan komunikasi. Analisi ini digunakan untuk membangunkan kerusi robot pintar berasaskan ECG dengan bantuan komunikasi (IRCC). IRCC melibatkan klasifikasi isyarat pelayaran (ke depan, kiri, kanan & rehat) dan isyarat-isyarat yang berkaitan dengan ucapan (ya, tidak dan Bantuan), untuk menyediakan satu sistem navigasi dengan bantuan komunikasi untuk pesakit DE. Dua puluh sihat naif-, umur-, dan jantina- yang memenuhi kriteria mengambil bahagian dalam prosedur pengumpulan data dimana isyarat EEG lapan saluran tanpa wayar dirakam. Dua paradigma ringkas dilaksanakan berdasarkan pemikiran (TEP) dan potensi visual (VEP) untuk menentukan korelasi antara dinamik otak dan IRCC. Tambahan pula, data-data yang dibangunkan dianalisis dalam mod ubahsuai dan mod umum. Isyarat gelombang otak yang diperolehi itu di pra-process untuk membuang gelombang gangguan dan dibahagikan kepada sampel yang sama panjang. Isyarat itu dikategorikan kepada enam jalur frekuensi, (iaitu Delta, Theta, Alpha, Beta, Gamma-1 dan Gamma-2), dan digunakan untuk mengektrak ciri-ciri tertentu. Untuk mengklasifikasikan IRCC, empat kaedah pengekstrakan frekuensi domain dibandingkan (spektrum perintah tinggi (HOS), analisis korelasi silang,analisis kuasa band (BP) dan ketumpatan kuasa spektrum (PSD)), dan tiga pendekatan yang berbeza berdasarkan teknik silang korelasi untuk menganggarkan saling bergantung di antara isyarat bingkai, jalur frekuensi dan kedudukan elektrod (iaitu ciri statistik menggunakan salib berkait rapat dua bingkai berturut-turut band spektrum berasaskan (CF), ciri-ciri statistik menggunakan silang dikaitkan bingkai gabungan berdasarkan jalur spektrum (CFB) dan ciri-ciri statistik menggunakan silang dikaitkan bingkai gabungan berdasarkan saluran elektrod (CEC)). Di samping itu, ciri-BP telah dianalisis dalam lima teknik yang berbeza untuk mengenal pasti perkaitan di antara IRCC dan spektrum kuasa dalam setiap jalur frekuensi, dan semua jalur frekuensi. Tiga klasifier berbeza seperti Rangkaian Neural banyak lapisan (MLNN), mesin sokong vektor (SVM), dan K- Jiran terdekat (KNN) telah digunakan untuk mengkaji prestasi semua ciri-ciri yang diekstrak. Skim sepuluh kali ganda-silang pengesahan telah digunakan untuk mengesahkan dan ujian kebolehpercayaan model pengelas. Daripada keputusan, dapat disimpulkan bahawa band analisis kuasa yang dicadangkan berdasarkan analisis frekuensi band individu telah mendapatkan ketepatan pengelasan minimum (Mean ± SD), 55.42% ± 2.29 untuk CC-TEP-CP, 63.80% ± 1.63 untuk CC-VEP- RA, 53.76% ± 5.85 untuk GC-TEP-CP dan 54.33% ± 2.25 untuk GC-VEP, yang menunjukkan bahawa jalur frekuensi individu mungkin tidak menggambarkan tugas IRCC. Manakala, analisis berdasarkan silang korelasi cadangan yang lebih baik dengan ketepatan pengelasan min maksimum 98.8% (TEP) mata pelajaran 17 dan 99.3% (VEP) bagi Subjek 17. Selanjutnya, sistem IRCC-GC mempunyai 89.44% ± 1.47 (min ± SD) untuk GC-TEP-

CEC-SD dan 88.93% ± 1.47 (Min ± SD) untuk GC-VEP-CEC-SD masing-masing. Keputusan yang diperolehi memberangsangkan dengan data eksperimen; ia boleh digunakan untuk mengemudi kerusi roda dan juga untuk komunikasi ucapan menggunakan paradigma ganjil.

Design and Development of a Thought Controlled Intelligent Robot Chair with Communication Aid

ABSTRACT

The fundamental movements like walking and speech communications are the basic needs of human beings in their daily life. Differentially Enabled (DE) communities have functional limitations that vary from primary/complicated activities such as weakening of the muscles, spasms, movement related problems, stroke, trouble swallowing and dysarthria. In these cases, Electroencephalogram (EEG) signals, being a measure of brain activity, which is responsible for the control of voluntary muscle movements through nervous system can be used to develop an alternative communication system or Brain Machine Interface's (BMI). This research focuses on analyzing different frequency domain algorithms to recognize the navigational tasks along with communication tasks to develop an EEG based intelligent robot chair with communication aid (IRCC). IRCC involves classification of navigational tasks (Forward, Left, Right & Relax) and tasks related to speech (Yes, No and Help), to provide a navigation system with communication aid for the DE patients. Twenty healthy naive-, age-, and gender-matched normal subjects were participated in the data collection procedure while eight-channel wireless EEG signal was being recorded. Two simple data acquisition paradigms were implemented based on thought evoked potentials (TEP) and visually evoked potentials (VEP) to determine the significant correlations between the brain dynamics and IRCC tasks. Furthermore, the developed database was analyzed in both customized modes and generalized modes. The recorded brain wave signals are preprocessed to remove the interference waveforms and segmented into frame samples of equal length. The frame signals are categorized into six frequency band signals, (namely Delta, Theta, Alpha, Beta, Gamma-1 and Gamma-2), and used to extract the features. To classify the IRCC tasks, four distinctive frequency-domain feature extraction methods were compared (namely higher order spectra (HOS), cross correlation analysis, band power (BP) analysis and power spectral density (PSD)). Also, three different approaches based on cross-correlation technique are proposed to estimate the interdependence between the frame signals, frequency bands and electrode positions (namely, statistical features using cross correlated two consecutive frames based spectral bands (CF), statistical features using cross correlated frame based combination of spectral bands (CFB), and statistical features using cross correlated frame based combination of electrode channels (CEC)). Further, the BP features were also analyzed in five different techniques to identify the interrelation between IRCC tasks and power spectrum in each frequency band, and all the frequency bands. Three different classifiers such as Multilayer Neural Network (MLNN), Support Vector machines (SVM), and K-Nearest Neighbor (KNN) were used to investigate the performance of all the extracted features. Ten-fold-cross-validation scheme was used for validating and testing the reliability of the classifier models. From the results, it is inferred that that the proposed band power analysis based on individual frequency band analysis has obtained minimal classification accuracy (Mean ± SD), 55.42 % ± 2.29 for CC-TEP-CP, 63.80 % ± 1.63 for CC-VEP-RA, 53.76 % ± 5.85 for GC-TEP-CP and 54.33 % ± 2.25 for GC-VEP, which shows that individual frequency bands may not reflect the IRCC tasks. Whereas, the proposed cross-correlation based analysis have better performance with a mean-maximum classification accuracy of 98.8 % (TEP) for subject 17 and 99.3 % (VEP) for Subject 17. Further, the IRCC-GC system has 89.44 % ± 1.47 (Mean ± SD) for GC-TEP-CEC-SD and 88.93 % ± 1.47 (Mean ± SD) for GC-VEP-CEC-SD respectively. Thus, the results obtained were promising with the experimental data; it can be used to navigate a wheelchair and also for speech communications using oddball paradigm.